Tantalum-based high-porosity carbides for radioactive ion beam production at ISOL facilities

Luca Egoriti

Politecnico di Milano and SCK•CEN

SCK•CEN mentor: Dr. Lucia Popescu

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Outline

- Introduction
  - ISOL targets
- Isotope release calculations
  - Methodology
  - Results of the benchmark study
- Summary & Outlook

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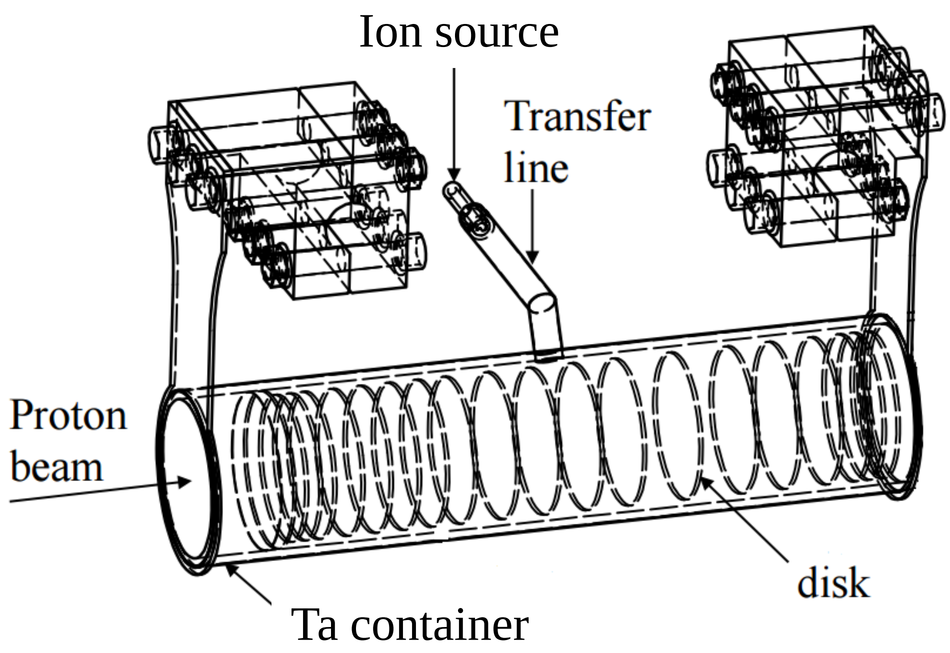
ISOL targets for Radioactive Ion Beam (RIB) production



RIB production processes:

- In target production
- Release processes:
  - Diffusion (solid)
  - Effusion (vacuum)
- Ionization, mass separation

RIB intensity:

$$I = \int \sigma(E) \Phi(E,x) \rho(x) \frac{N_{av}}{A} \, dx \, dE \; \varepsilon_{Diff} \varepsilon_{Eff} \varepsilon_{Ion} \varepsilon_{MS}$$

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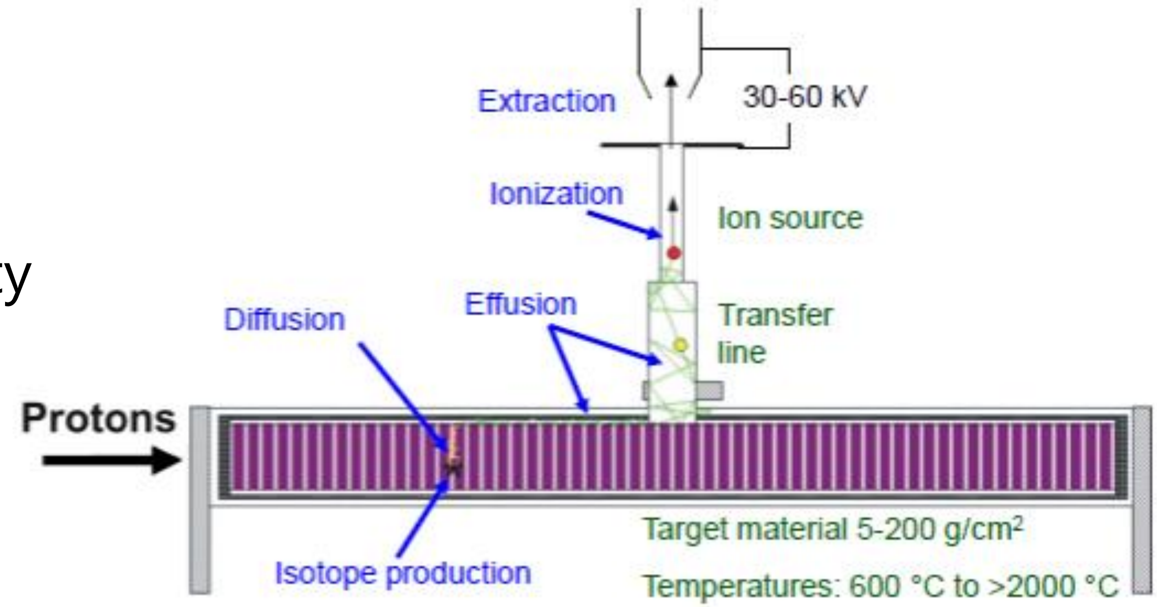
Requirements

- High cross sections for isotope production
- Minimize diffusion & effusion time
- High thermal conductivity
- High resistance to radiation damage & thermal shocks



Target materials: e.g. refractory (Ta) metal and (TaCx) carbide

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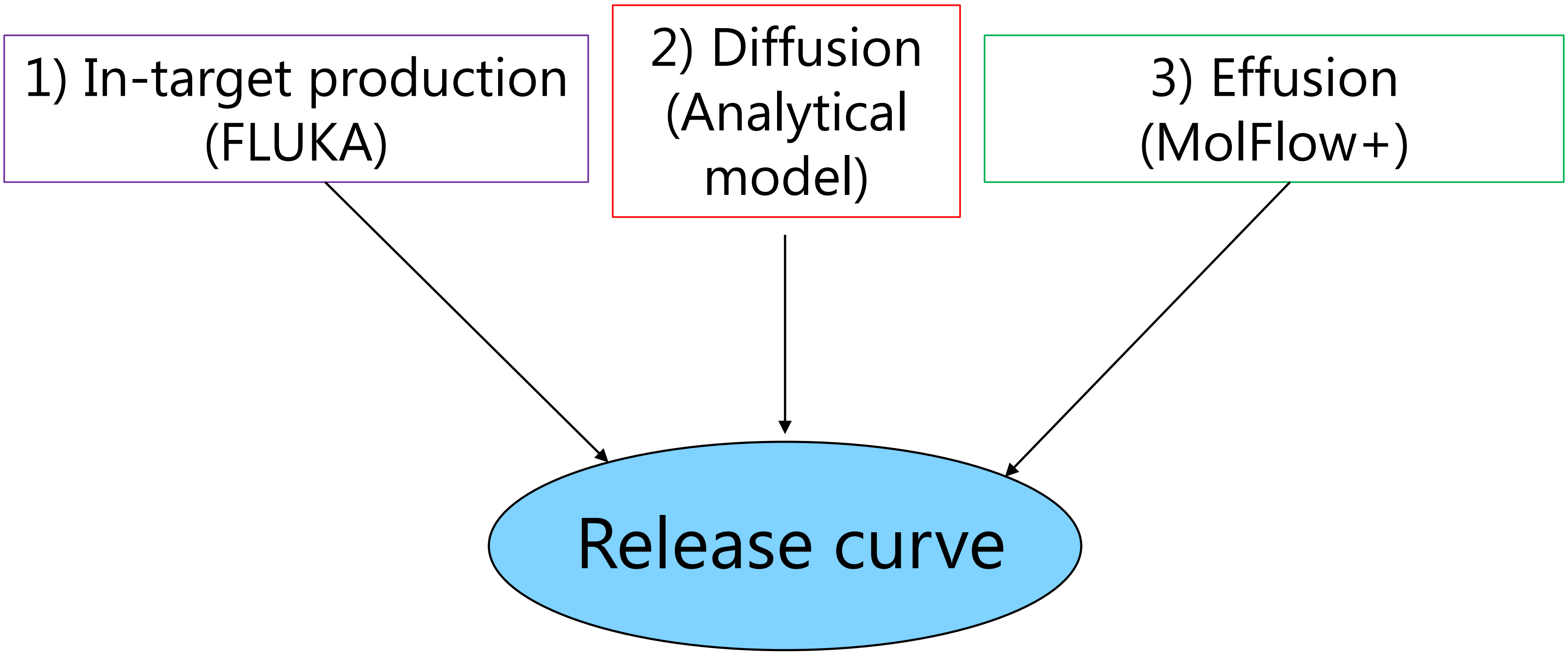
Isotope release calculations - Methodology



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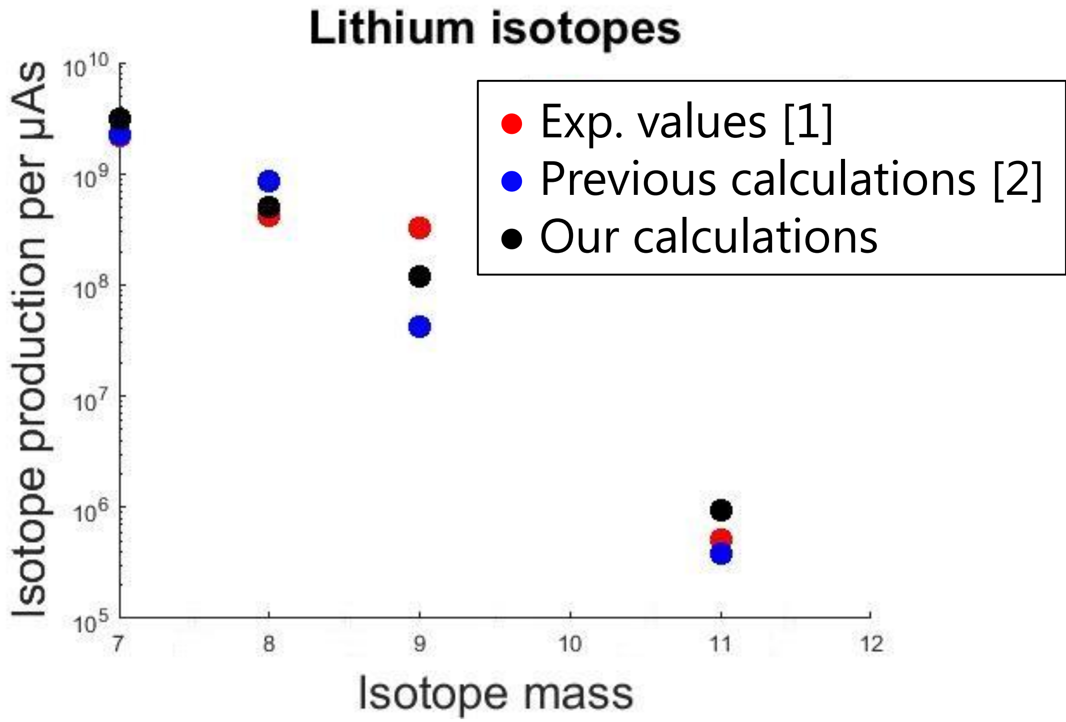
1) IN-TARGET PRODUCTION

(FLUKA simulation)



[1] U.C.Bergmann et al. Nuclear Physics A 701 (2002) 363c–368c
[2] R. Silberberg, C.H. Tsao, Astrophys. J. Suppl. Ser. 220 25 (II) (1973) 335.

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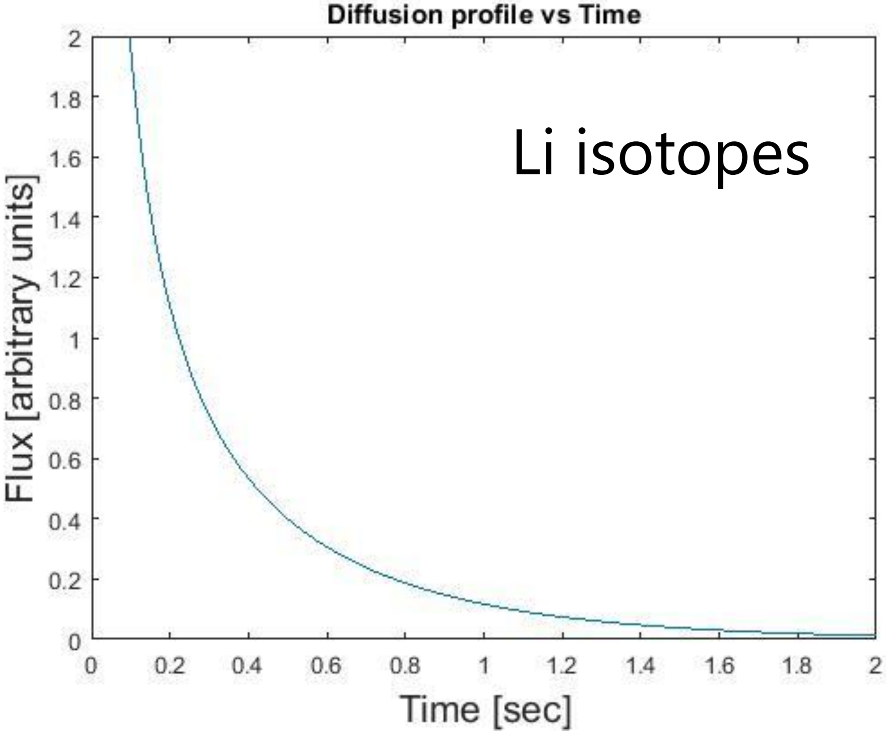
2) DIFFUSION ε_{Diff}

- $\frac{\partial C(x,t)}{\partial t} = D\, \nabla^2 C(\boldsymbol{x}, t)$
- Solution: concentration profile
- Flux: $\boldsymbol{J} = -D\, \nabla C$
- Arrhenius dependence:

$$D = D_0\, e^{-\frac{E_a}{RT}}$$



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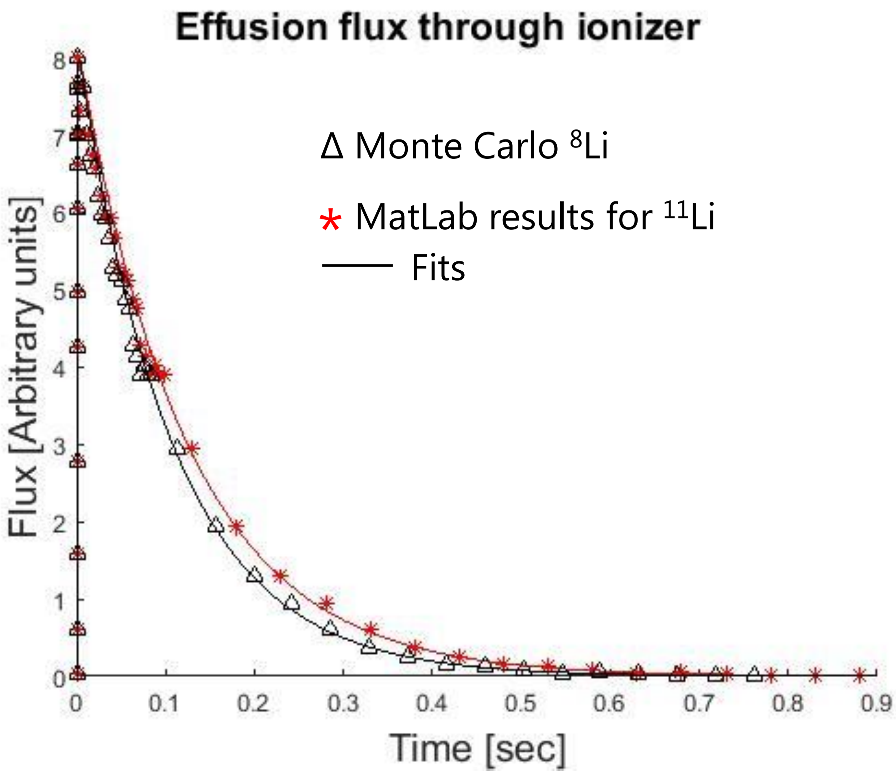
3) EFFUSION ε_{eff}

- Monte Carlo code (MolFlow+): ideal effusion profile (no re-absorption)
- MATLAB analysis to get results:
  - At a different operational temperature
  - For a different isotope
  - For non-zero sticking times

$$\tau_s = \tau_0 \, e^{-\frac{\Delta H_a}{RT}}$$

- Fit with analytical function
  - $E(t) = A * (1 - e^{-Bt}) * e^{-Ct}$



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Isotope release calculations - Methodology

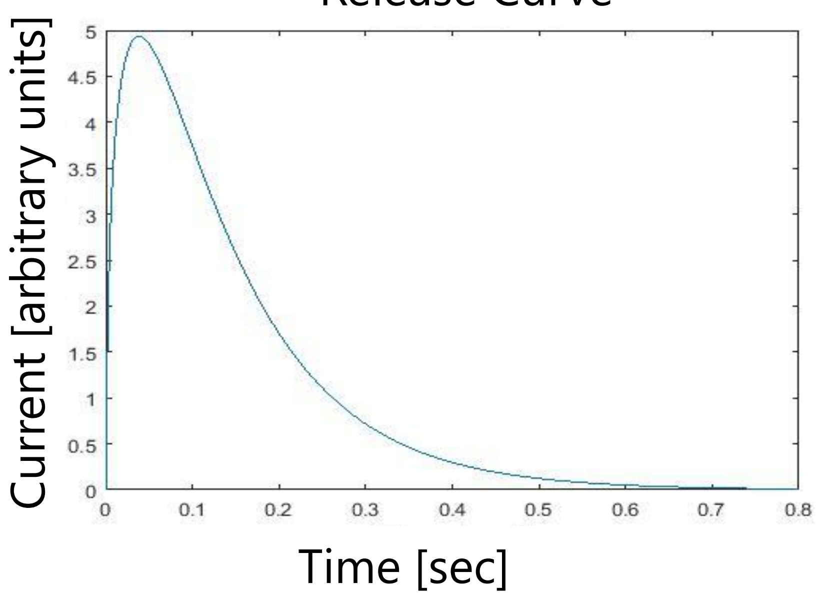
- Convolution of diffusion and effusion curves to get the overall isotope release curve

$$R(\mathrm{t}) = e^{-\lambda t} * \int_0^t D(t') * E(t-t')\, dt'$$

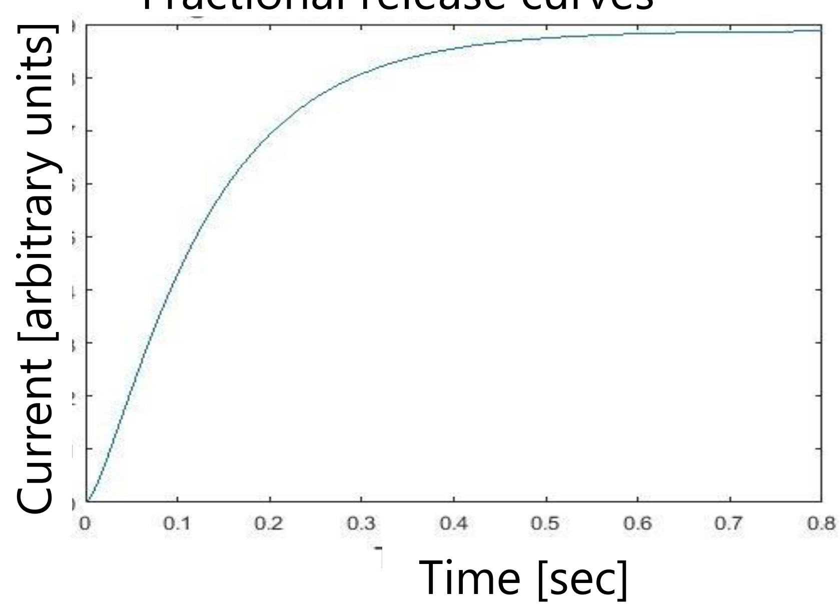
- Integration to get the fractional release

$$I(t) = \int_0^t R(t')dt'$$

Release Curve



Fractional release curves



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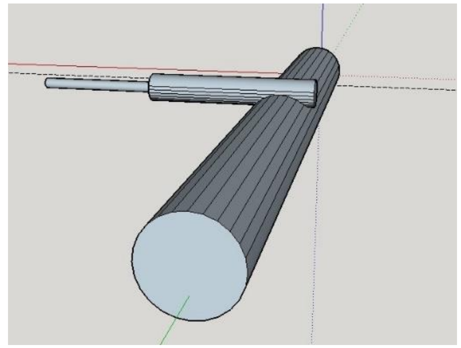
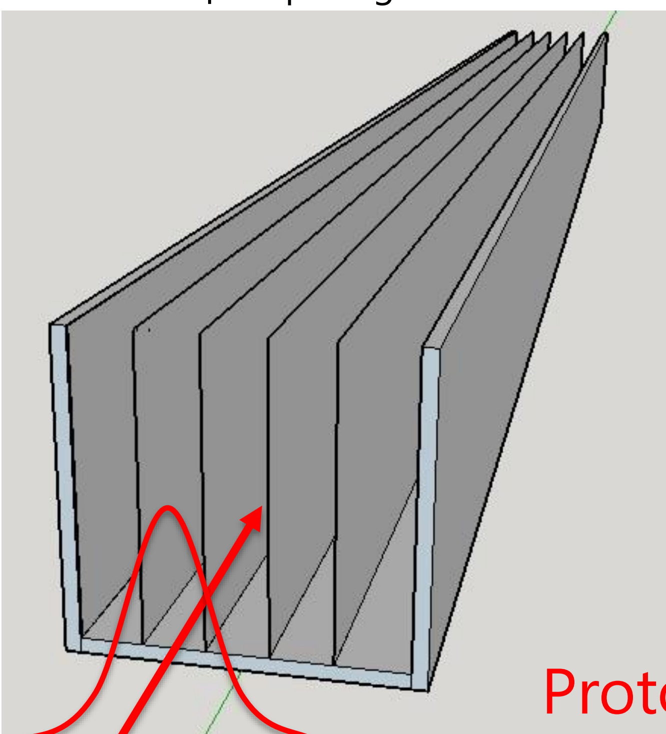
Isotope release calculations – two geometries used at ISOLDE

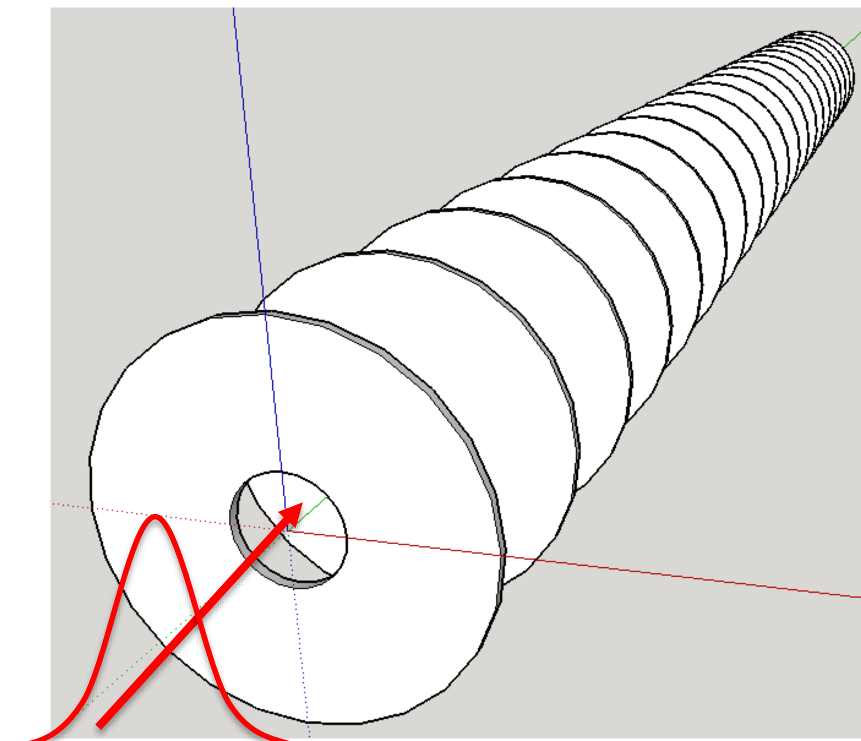


200 tantalum foils
2 µm thick 15 cm long
50 µm spacing

3600 tantalum annular discs (RIST-ISOLDE geometry)
25 µm thick 8.75mm diameter
25 µm spacing



Proton beam



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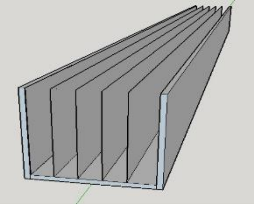
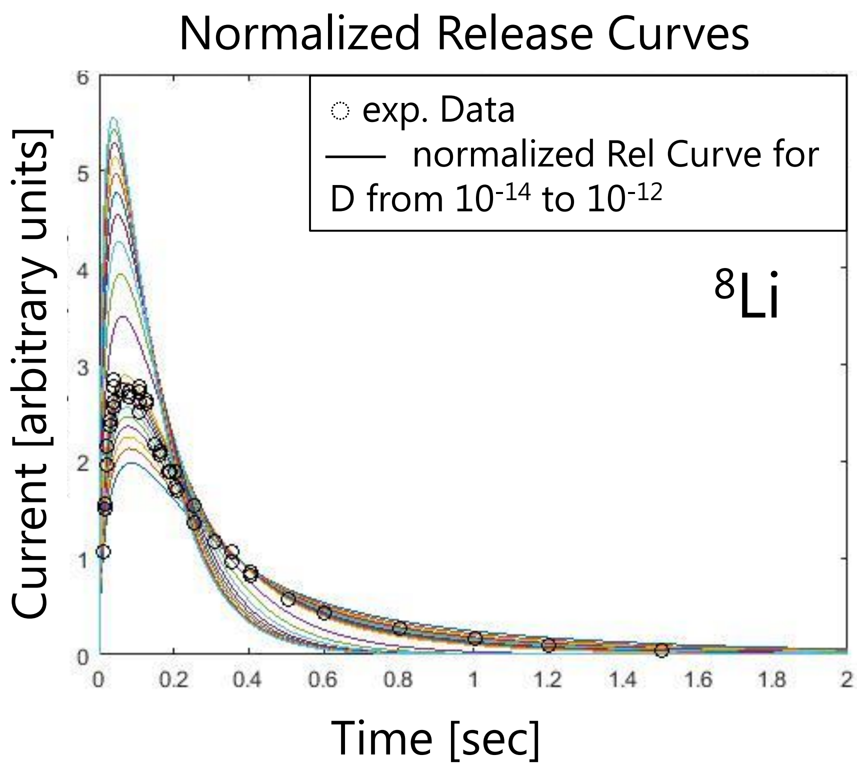
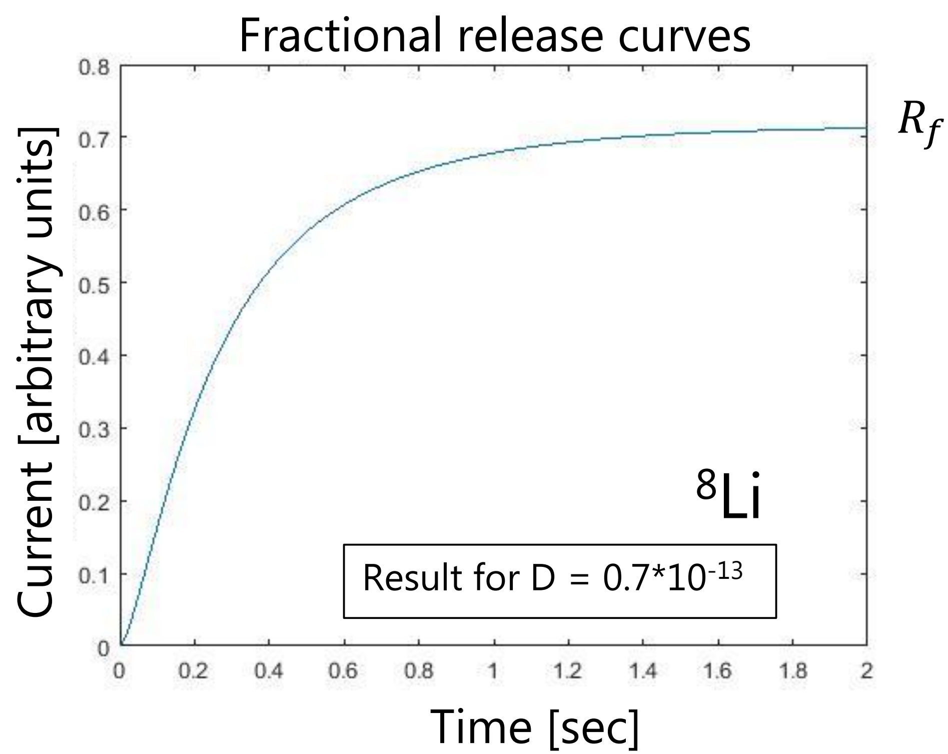


Isotope release calculations - Results

Tantalum foil target: ^{8}Li





Release fractions (R_f)

- Our simulation: R_f = 71% (D = $0.7\ 10^{-13}\ [\frac{m^2}{s}]$)
- Previous data analysis from literature: R_f = 75% (D = $10^{-12}\ [\frac{m^2}{s}]$)

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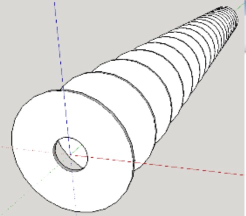
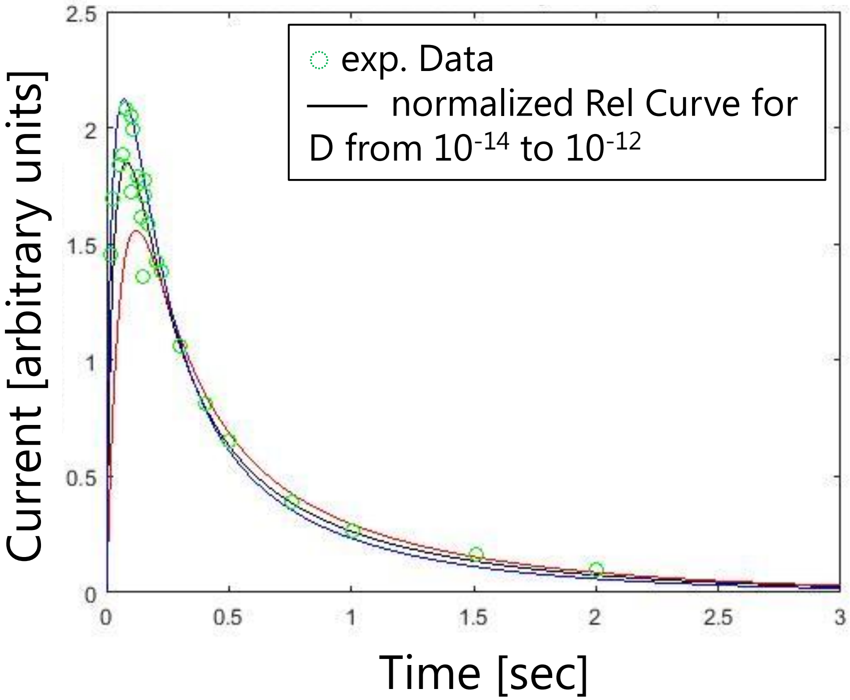


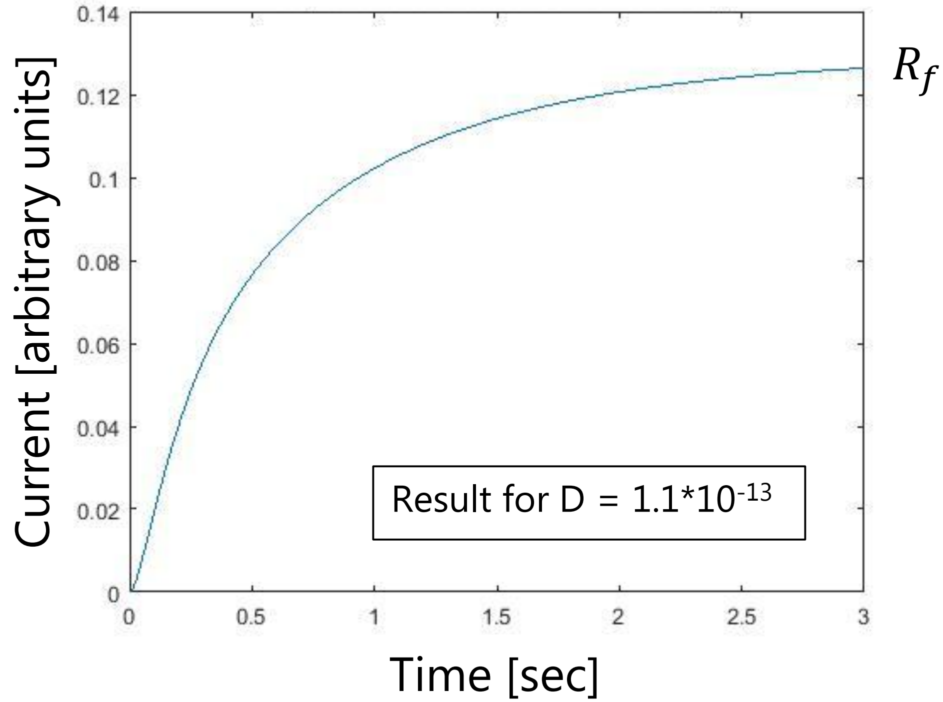
Isotope release calculations - Results

RIST- ISOLDE target: ^{8}Li

Normalized Release Curves



Fractional release curves



Release fractions (R_f)
- Our simulation: R_f = 12.6% (D = $1.6\ 10^{-13}\ [\frac{m^2}{s}]$)
- Literature: No previous analysis

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Summary & Outlook

- Potentiality of tantalum-based high-porosity carbides as target material for ISOL facilities.

- Isotope release model developed, combining:
  - Analytical release curve
  - Detailed Monte Carlo model

- Benchmark on tantalum targets operated at ISODLE

- Outlook
  - The same methodology to be applied on high-porosity target materials
  - Target-design optimization based on this method
  - Thermal analysis of the target

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Thank you for your attention

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